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Extreme BAL Quasars from the Sloan Digital Sky Survey

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Abstract. The Sloan Digital Sky Survey has discovered a population of broad absorption line quasars with various extreme properties. Many show absorption from metastable states of Fe II with varying excitations; several objects are almost completely absorbed bluewards of Mg II; at

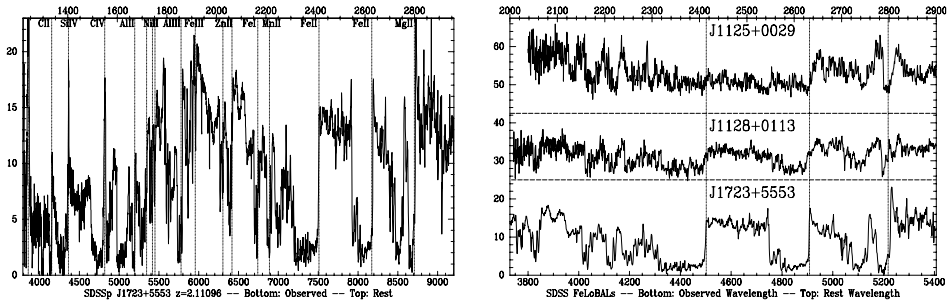

Figure 1. BALs with Fe II* absorption. a) SDSS 1723+5553, z=2.11. b) Comparison of 2000-2900Å regions in SDSS 1723+5553 (bottom) and two lower-z FeLoBALs, SDSS 1128+0113 (middle, z=0.894) and SDSS 1125+0029 (top, z=0.865); dashed lines show zero flux for each, and vertical dotted lines show Fe II*2414Å & 2632Å and Mg II 2798.

least one shows stronger absorption from Fe III than Fe II, indicating temperatures T>35000 K in the absorbing region; and one object even seems to have broad Hβ absorption. Many of these extreme BALs are also heavily reddened, though 'normal' BALs (particularly LoBALs) from SDSS also show evidence for internal reddening.

1. Introduction

The Sloan Digital Sky Survey (York et al. 2000) is using dedicated instruments on a 2.5m telescope (Gunn et al. 1998) to image 10^4 deg^2 of sky to $\sim 23^m$ in five bands (Fukugita et al. 1996) and obtain spectra of $\sim 10^6$ galaxies and $\sim 10^5$ quasars selected primarily as outliers from the stellar locus. Its area, depth, and selection criteria make SDSS effective at finding unusual quasars. The first data release (Stoughton et al. 2001, in prep.). contains ~4500 spectroscopically confirmed quasars, including ~200 BALs, a few percent of which have extreme properties of one sort or another. All these extreme BALs are LoBALs, which show absorption from both low- and high-ionization transitions, instead of the more common HiBALs with only high-ionization absorption. Full analysis is underway (Hall et al. 2001, in prep.), but already these objects confirm the existence of a population of extreme BALs, as suspected from previous discoveries of individual extreme BALs (Becker et al. 1997, Djorgovski et al. 2001).

2. BAL Quasars With Fe II* Absorption

The rare LoBAL quasars with absorption from metastable excited states of Fe II (Fe II*) have been dubbed FeLoBALs (Becker et al. 2000; Hazard et al. 1987; Menou et al. 2001). They are valuable because photoionization modelling of them can constrain n_e in the BAL clouds (e.g. de Kool et al. 2001). Fig. 1a shows a spectacular example, SDSS 1723+5553, with absorption

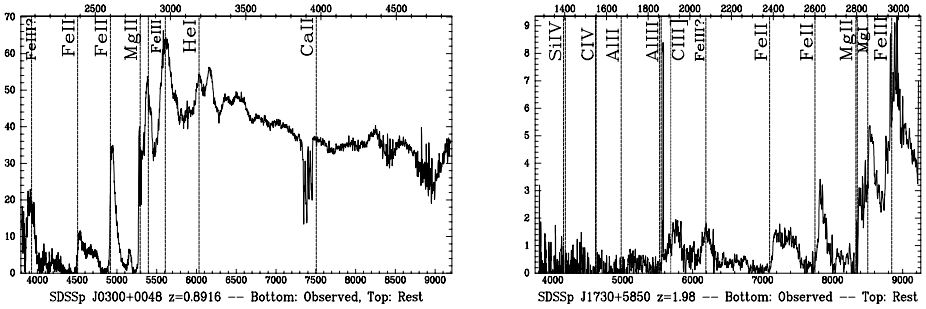

Figure 2. SDSS LoBALs with strong absorption blueward of Mg II. a) SDSS 0300+0048 at z=0.8916. b) SDSS 1730+5850 at z=1.98.

from over twenty transitions in at least a dozen elements. Fig. 1b compares SDSS 1723+5553 to two lower-z FeLoBALs with [O II] emission line redshifts. Both low-z objects show Fe II* absorption blueward of 2414Å and 2632Å from states up to ∼1 eV above ground, but SDSS 1125+0029 also shows absorption near 2500 Å from even more excited levels. In both low-z objects, the Mg II BAL absorption apparently extends 2000 km s^{-1} *redward* of the systemic z.

Some SDSS FeLoBALs show very abrupt drops in flux near Mg II λλ2796,2803 (e.g. SDSS 0300+0048 in Fig. 2a). SDSS 0300+0048 has associated Mg II absorption at z=0.8916, at least 4 narrow Ca II H&K absorption systems located 2350 to 3900 km s^{-1} blueward of the Mg II system, and broad Ca II absorption extending a further 2000 km s^{-1} blueward. Broad, near-total Mg II absorption is associated with the highest-z Ca II system, but broad Fe II* absorption is associated instead with the *strongest* Ca II system, at slightly lower z. Fig. 2b shows SDSS 1730+5850, which is clearly a higher redshift analogue of SDSS 0300+0048. Our spectrum extends farther into the UV for this z∼2 object, and shows a weak recovery at C III] λ1908 but essentially zero flux below Al II λ1670. Quasars such as these at $z \geq 2$ will obviously be greatly underrepresented in optical surveys.

3. BAL Quasars With Fe III Absorption

Fig. 3 shows SDSS 2215−0045, a LoBAL at z=1.47548 (measured from associated Mg II absorption, as with SDSS 0300+0048). Its absorption troughs are unusual for a LoBAL: they are very broad, detached, and strongest near the high velocity end rather than at low velocity. By comparison to SDSS 1723+5553 (Fig. 1), we initially identified the strong trough at λ_{obs}∼4900Å as Cr II. However, the implied abundance of Cr relative to Mg is implausible, and the expected corresponding Zn II is missing. We now believe this absorption is due to Fe III (multiplet UV 48), with additional Fe III (UV 34) absorption at λ_{obs}∼4500Å, redward of Al III. Since Fe II absorption is weak or absent, the large Fe III/Fe II ratio suggests that the BAL clouds in this object have T>35000 K, sufficient to collisionally ionize Fe II to Fe III. Fe III absorption is seen in several other SDSS LoBALs (e.g. Fig. 4) and in a few previously known LoBALs, but nowhere as strongly (alone or relative to Fe II) as in SDSS 2215−0045. Note the different

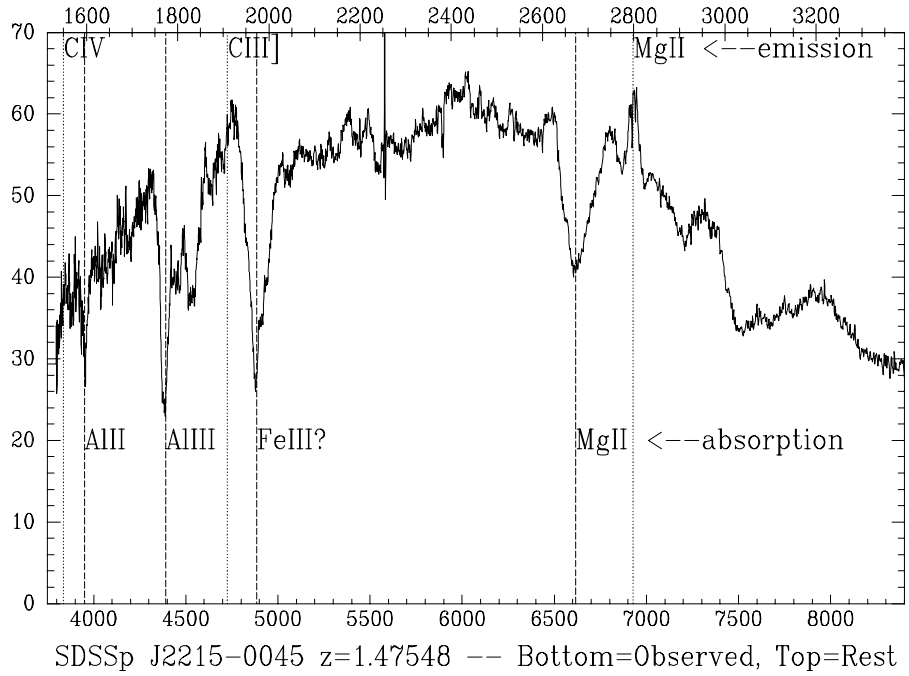

Figure 3. SDSS 2215−0045 at z=1.47548. Note the absence of strong Fe II absorption at 2200–2600Å in the rest frame.

spectral slopes blueward & redward of ∼2400Å, indicating reddening which must occur outside the BAL region since dust cannot survive long at T>35000 K.

4. A LoBAL With Broad Hβ Absorption

Fig. 4 shows an optical (Keck) plus NIR (UKIRT) spectrum of SDSS 0437-0045 which reveals a strongly absorbed quasar with z=2.74389 from [O III]. The absorption extends 2900 km s^{-1} redward of this z (cf. Fig. 2b). Even more remarkable is the probable presence of Hβ absorption nearly 10^4 km s^{-1} wide and of REW∼100 Å. Hβ absorption in AGN has previously been seen only in NGC 4151 (Anderson & Kraft 1969; Sergeev et al. 1999), but with ≤1000 km s^{-1} width and ≤3 Å REW. This object is also unusual because the FeIII trough at ∼2070Å has been seen to vary with nearly unprecendented amplitude and speed.

5. Heavily Reddened BAL Quasars

SDSS has found evidence for a population of red quasars (Richards et al. 2001), and BALs in general are redder than the typical quasar (Menou et al. 2001), but for the most extreme objects the reddening is unambiguous. Fig. 5 shows SDSS 1456+0114, an extremely reddened LoBAL (and FIRST source) at z=2.367 (measured from weak C III], the only broad line visible). Several other similar objects have been found by SDSS, but with even weaker broad emission. Since

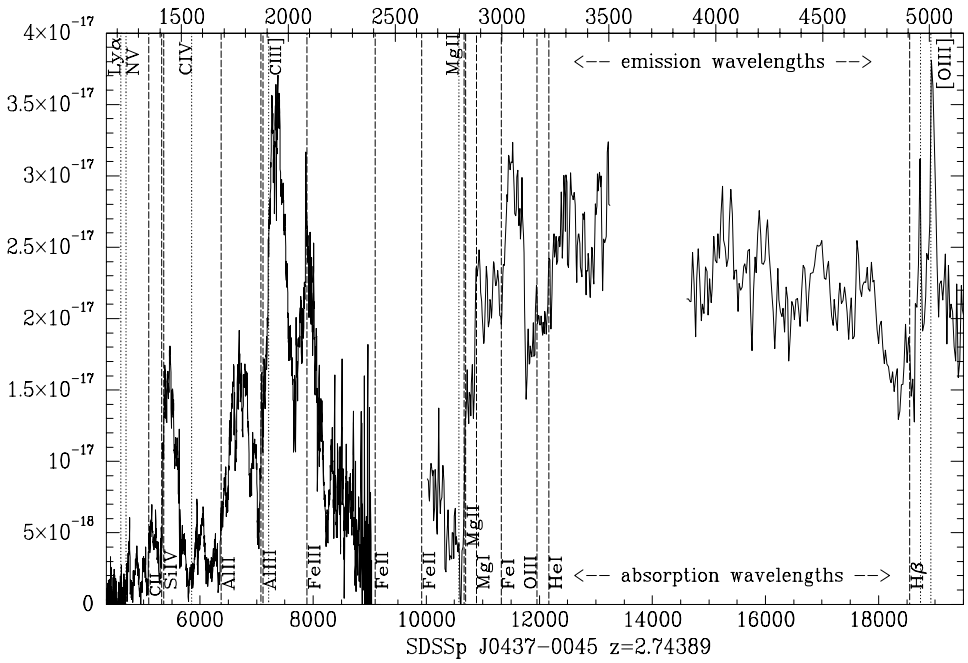

Figure 4. Optical-NIR spectra of SDSS 0437−0045 at z=2.74389. Strong lines are labelled at the expected wavelengths for emission (top) and absorption (bottom). Note the nearly complete absorption near the expected wavelength of C IV, and the probable broad Hβ absorption.

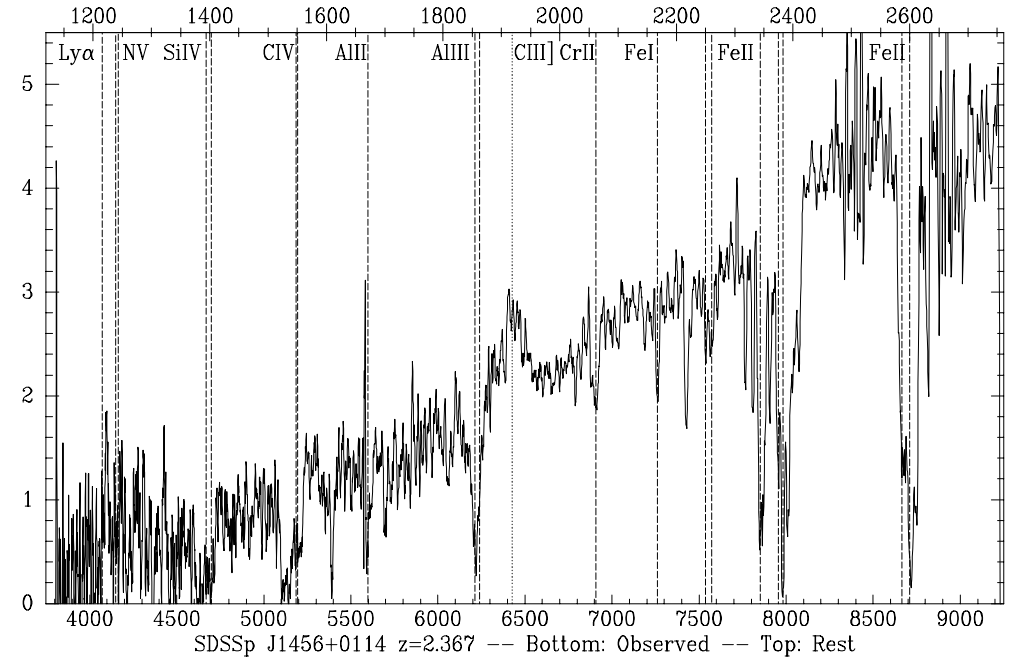

Figure 5. SDSS 1456+0114, an extremely reddened LoBAL at z=2.367.

reddening does not affect equivalent widths, this may indicate that in these objects the broad line region is even more heavily reddened than the continuum. This would be quite plausible if most of the continuum light in those objects is scattered light, a hypothesis which can easily be tested with polarization data.

6. Discussion

'Well, that was disturbing.' —Fred Hamann, after this talk at the meeting.

We prefer to view these objects as invigorating. The area and depth of SDSS, plus its simple selection of quasar candidates as outliers from the stellar locus, makes it efficient at finding quasars with unusual properties. Moreover, the discovery of typically several examples of each type of extreme LoBAL quasar presented here means that a *population* of extreme LoBAL quasars exists and that only now, with SDSS, are we beginning to sample the full range of properties that exist in BAL outflows, and thus around quasars on the whole.

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References

Anderson, K., & Kraft, R. 1969, ApJ, 158, 859

Becker, R., Gregg, M., Hook, I., McMahon, R., White, R., & Helfand, D. 1997, ApJ, 479, L93

Becker, R., et al. 2000, ApJ, 538, 72

de Kool, M., et al. 2001, ApJ, 548, 609

Djorgovski, S. G., et al. 2001, to appear in Mining the Sky, eds. A. Bandel et al. (Berlin: Springer-Verlag) (astro-ph/0012489)

Fukugita, M., Ichikawa, T., Gunn, J., Doi, M., Shimasaku, K., & Schneider, D. 1996, AJ, 111, 1748

Gunn, J. E., & The SDSS Collaboration 1998, AJ, 116, 3040

Hazard, C., McMahon, R., Webb, J., and Morton, D. 1987, ApJ, 323, 263

Menou, K., & The SDSS Collaboration 2001, ApJ, in press (astro-ph/0102410)

Richards, G. T., & The SDSS Collaboration 2001, AJ, 121, 2308

Sergeev, S., Pronik, V., Sergeeva, E., & Malkov, Y. 1999, A&A 341, 740

York, D. G., & The SDSS Collaboration 2000, AJ, 120, 1579